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Human Brain Project

Hardware Software Science Co-design in the Human Brain Project

Wouter Klijn

29-11-2016 Pune, India

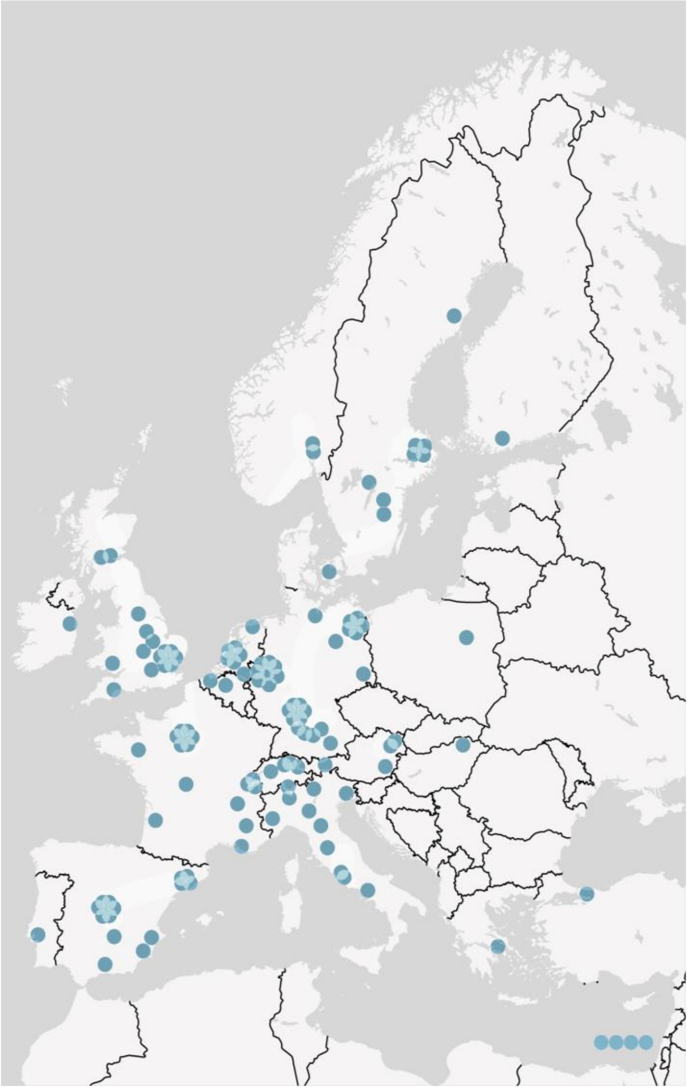
Content

- The Human Brain Project
- Hardware
    - HBP Pilot machines
- Software
    - A Neuron
    - NestMC: NEST Multi Compartment
- Science use-case
    - Large brain areas
    - Cortical dynamics
- Summary / discussion

Human Brain Project

- Future and Emerging Technologies Flagship project

- More than 400 scientists from 112 institutions representing 24 countries



"Flagships are visionary, science-driven, large-scale research initiatives addressing grand Scientific and Technological challenges"

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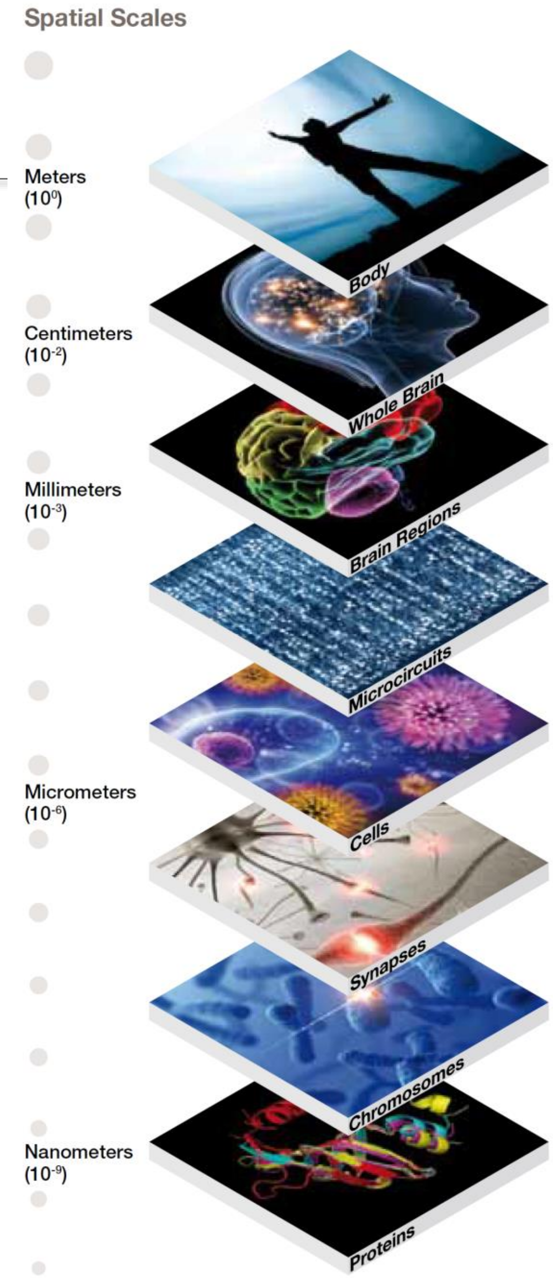
Human Brain Project

- A 10-year €1 billion Euro project
- Mental health: €800 per year billion in Europe

Challenges

- The most complex object in the known galaxy
- Multiple scales
- Multiple organizational levels
- Brain uses 30 Watt for 100 Billion neurons



Human Brain Project Objectives

- Simulation of the brain
- Brain-inspired computing and robotics
- Interactive supercomputing
- Map brain diseases
- HBP Brain Atlas

- Integrated European scientific research infrastructure
- Sustainable organization
- Research and collaboration

- Full brain scale
- 30 Watts
- Scientist in the HPC loop
- Big-data patient data
- Merge multi level data

- Supporting science
- Long term vision
-

HBP pilot systems

Julia (Ju + glia)

Juron (Ju + neuron)

HBP Pilot systems

- Observation: Mismatch between science needs and currently available systems
- Research (Pre) Exascale supercomputing architectures
- Drivers:
  - Dense Memory Integration
  - Dynamic resource management
  - Scalable visualization and steering
- Tender to prospective suppliers

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Julia

- **CRAY, CS-400 / CS-Storm**
- **Compute Nodes (60):**
  - Intel KNL (Xeon Phi) 7230 @ 1.30GHz
  - 64 cores (x4), 96GB DDR4, 16GB MCDRAM
- **Visualization Nodes (4):**
  - Intel Broadwell, 28 cores, 128GB DDR4
  - 4 NVIDIA GPU K40
- **Connectivity:**
  - Intel 100GB OmniPath
  - 10GB Uplink
- Dense Memory Integration
  - 4 DataWarp Nodes, Intel Broadwell, 28 cores, 128GB DDR4
  - 2 NVMe, Intel P3600, 1.6 TB

Juron

- **IBM/NVIDIA, Minsky**
- **Compute Nodes (18):**
  - POWER8 @3.32Ghz 20 cores (8SMT), 256 GB DDR4
  - 4x NVIDIA Pascal 100, NVLink
- **Visualization Nodes (4):**
  - 4 Pascal 100, NVLink
- **Connectivity:**
  - Mellanox Connectx4 100GB EDR Infiniband
  - 10GB uplink, NVLink
- **Dense Memory Integration**
  - HGST SN100 series, 1.6 TB

NEST Multi Compartment : NestMC

nest:: initiative

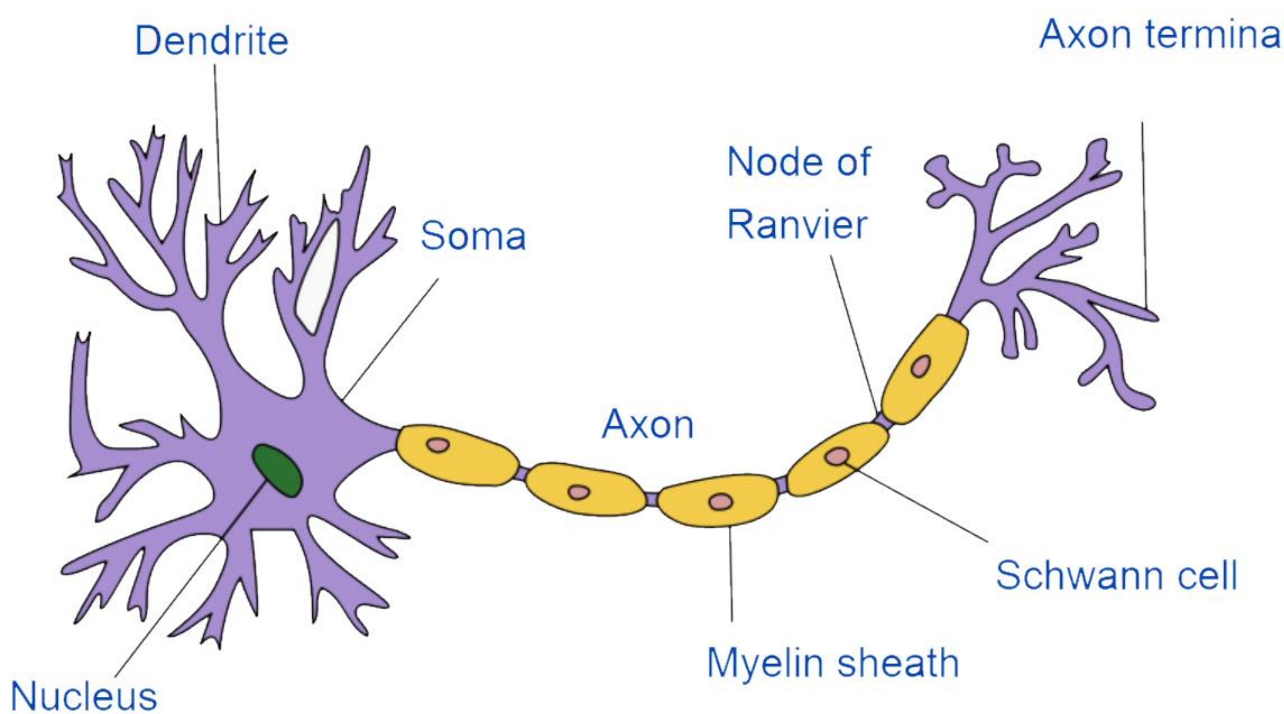
CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

BSC
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

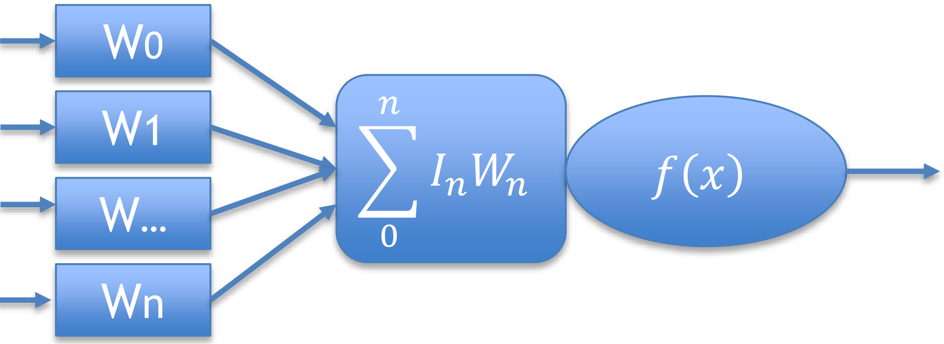
JÜLICH
FORSCHUNGSZENTRUM

NestMC

- CSCS
  - Ben Cumming
  - Stuart Yates
  - Vasileios Karakasis
- Julich
  - Alexander Peyser
  - Wouter Klijn
  - Yachau Shau
- BSC
  - Ivan Martinez
  - Pedro Valero

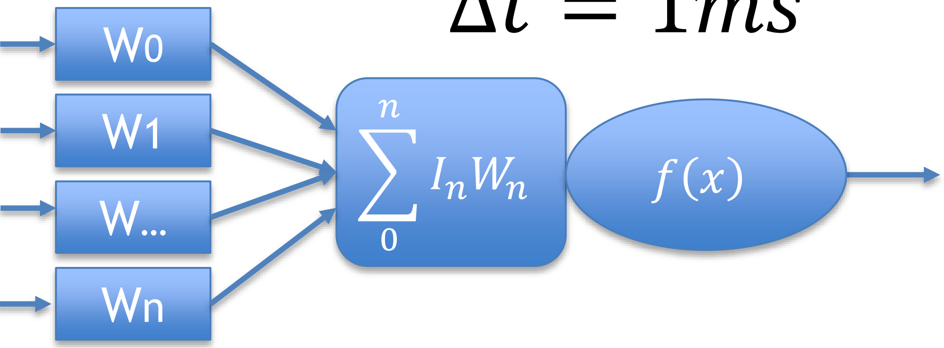


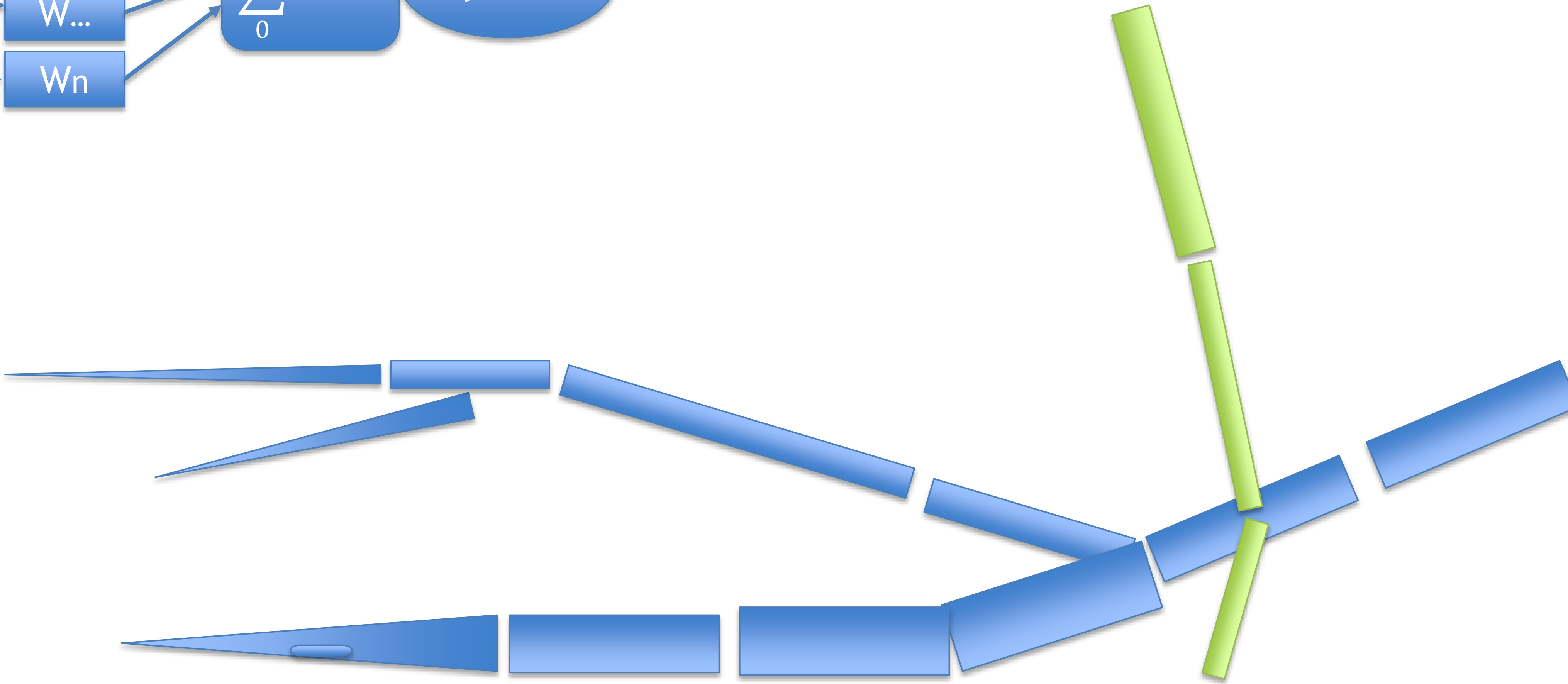
NestMC vs Artificial Neuron



NestMC vs Artificial Neuron

$$\Delta t = 1ms$$





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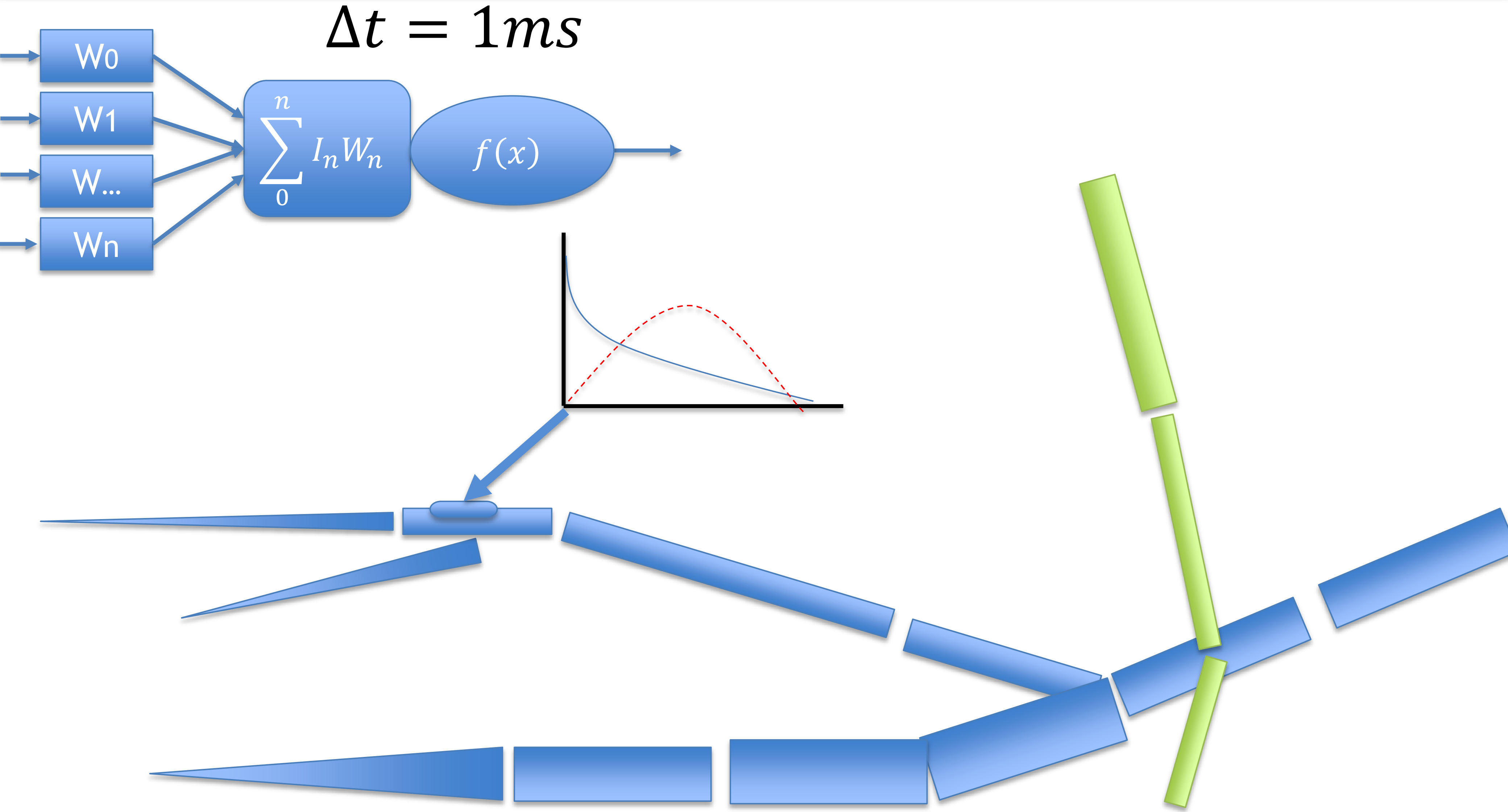

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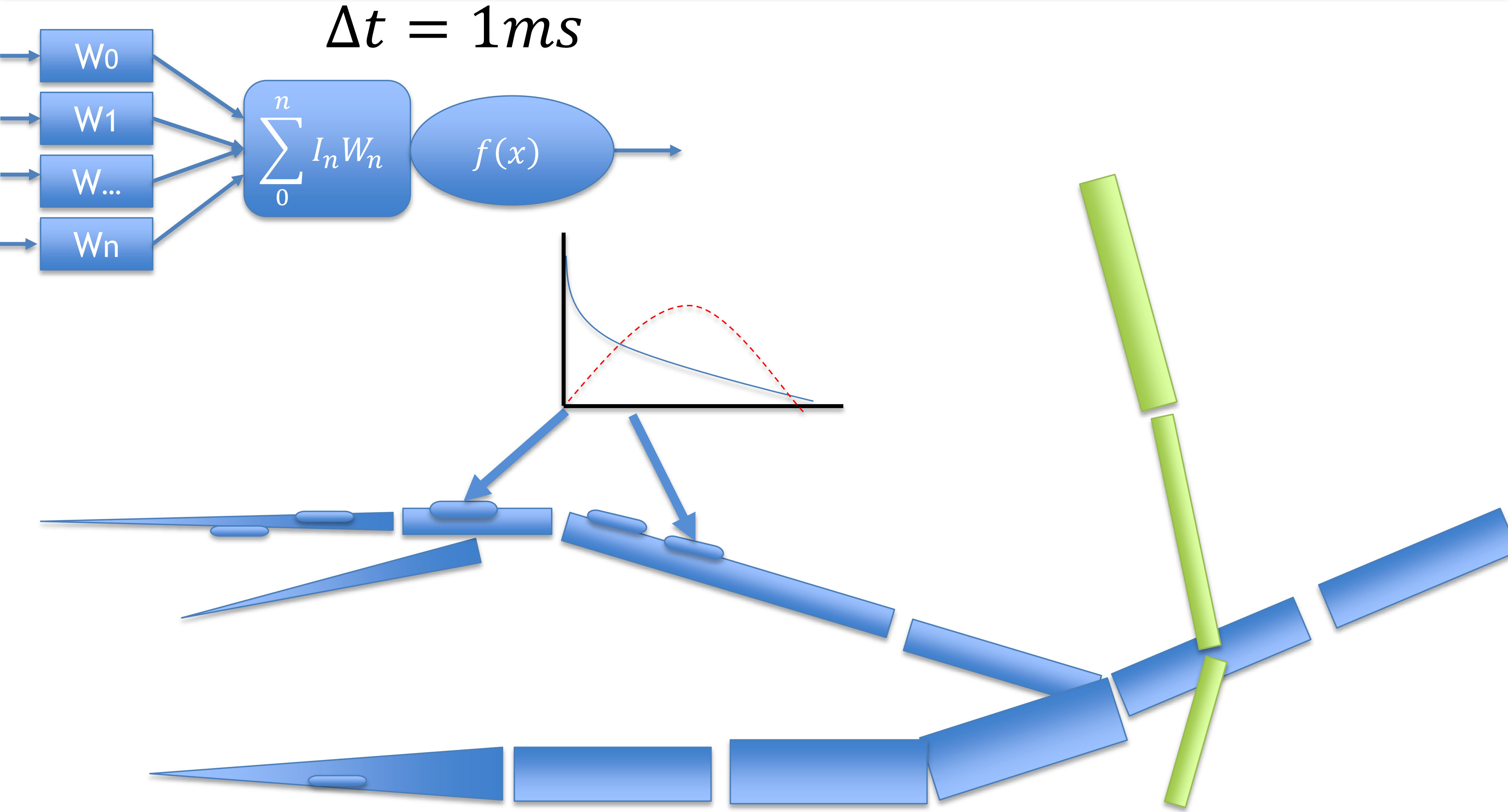

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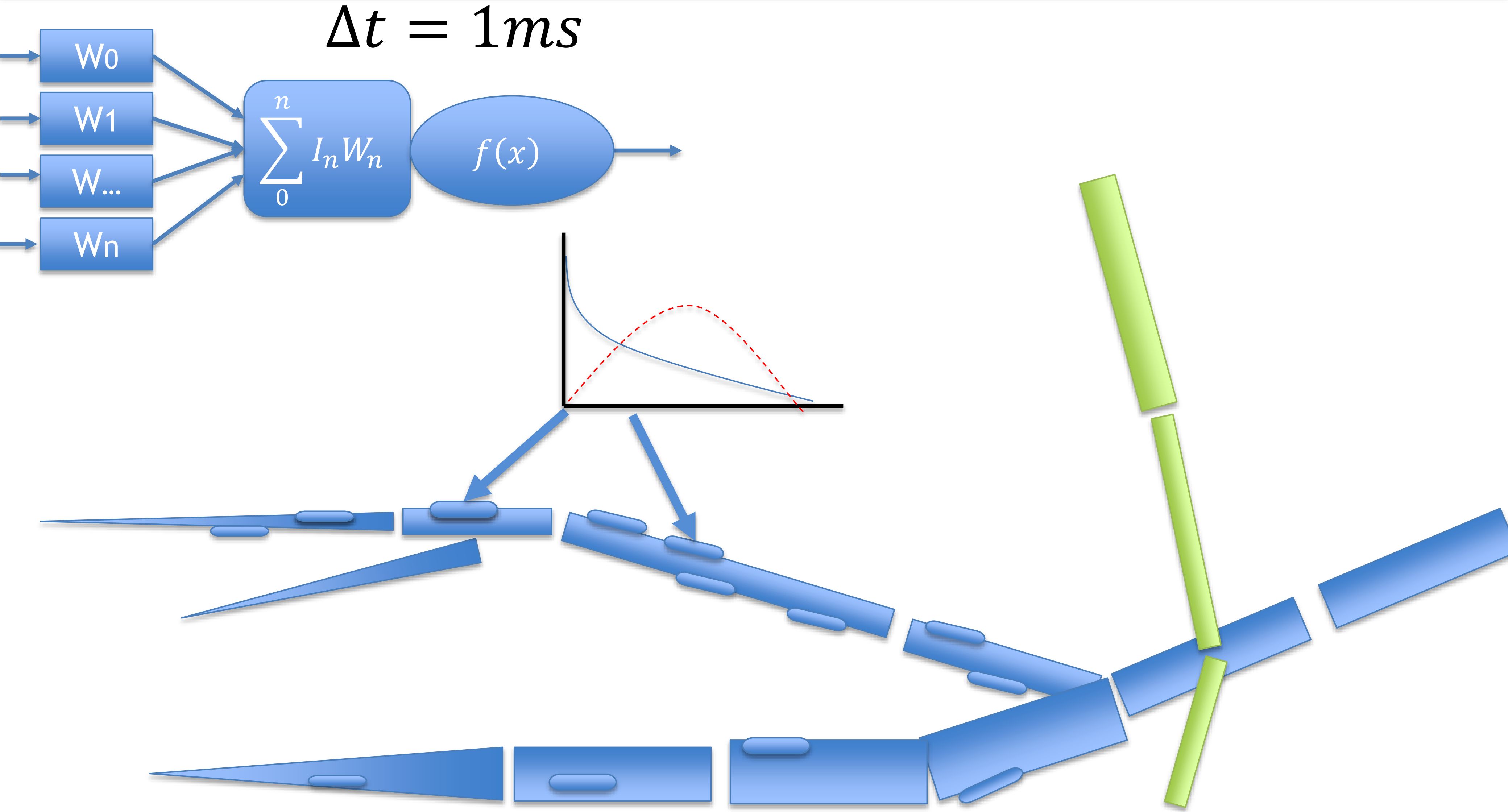

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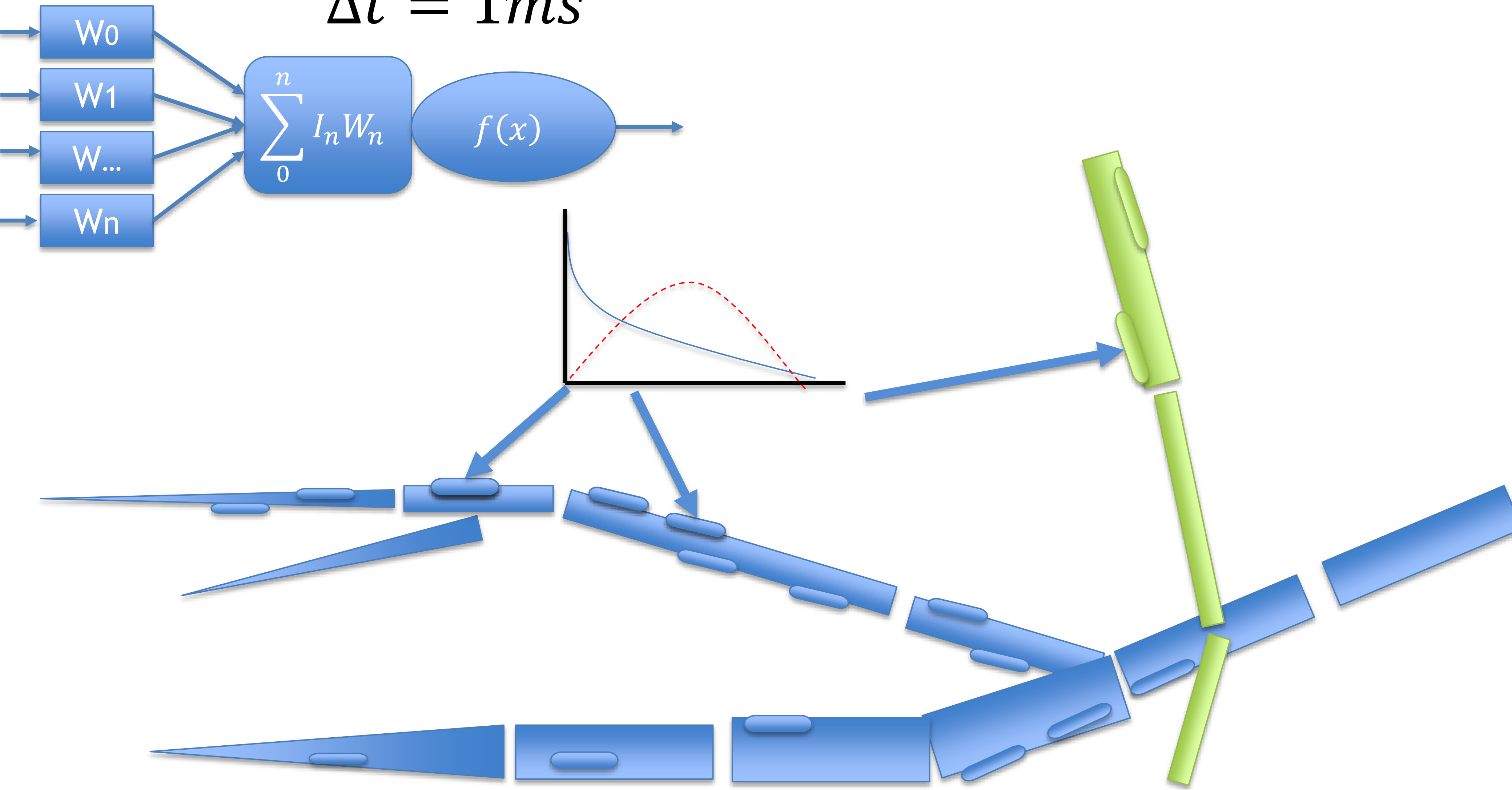

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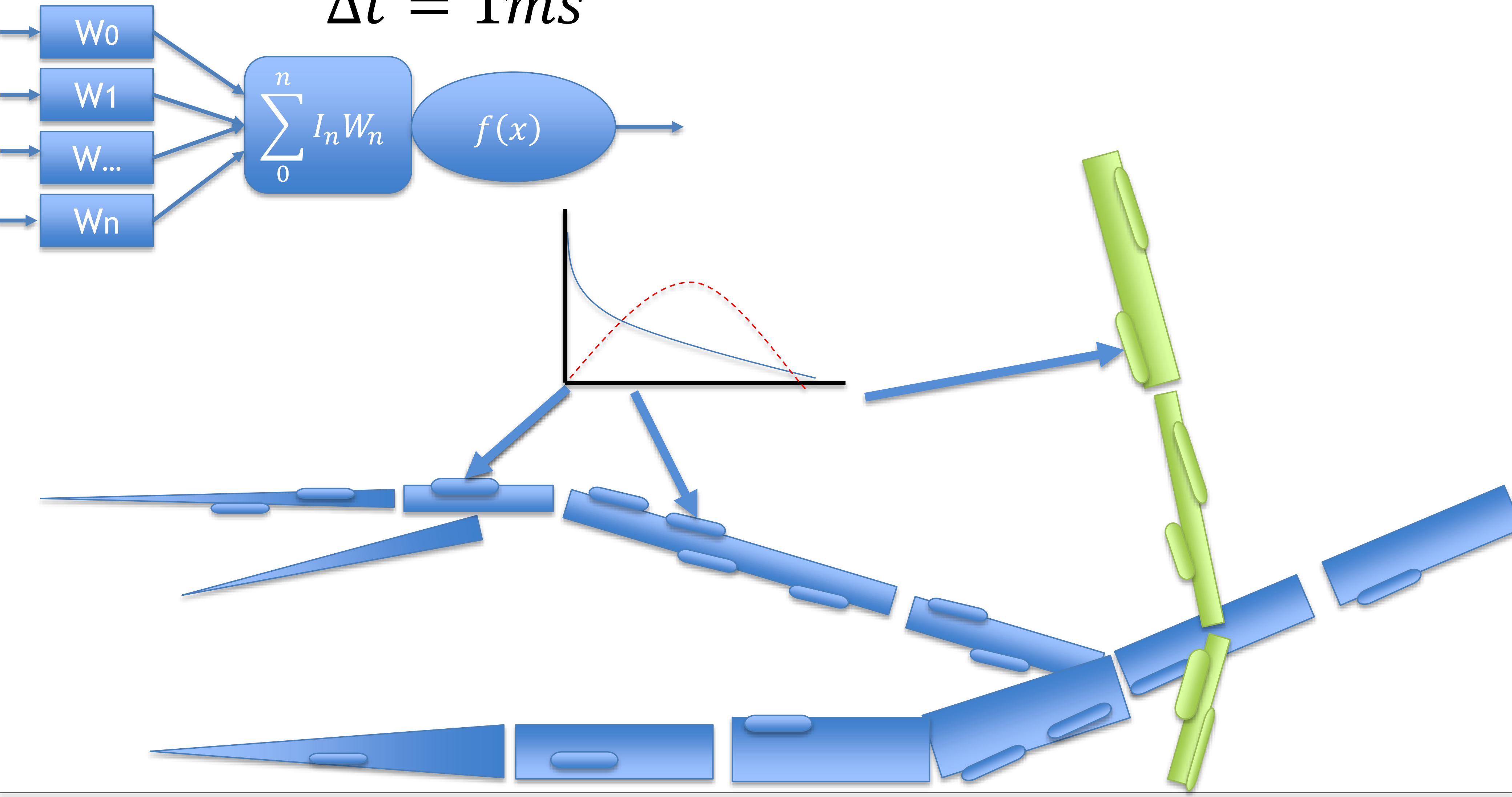

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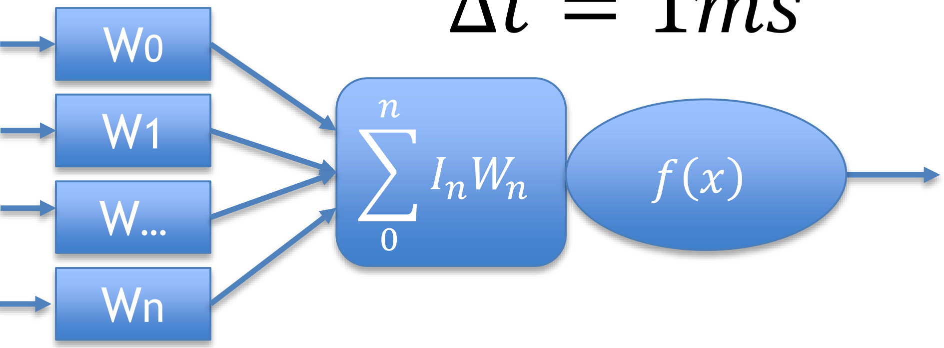

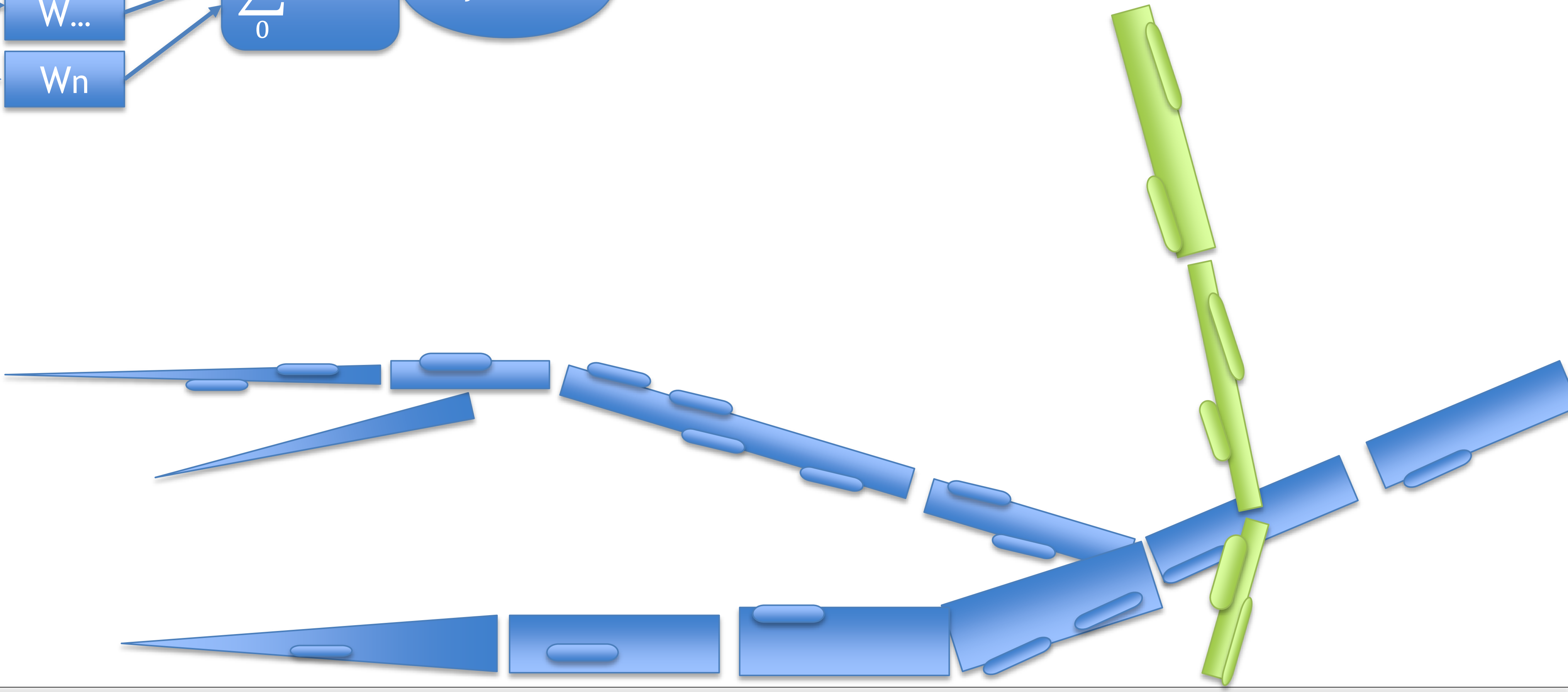

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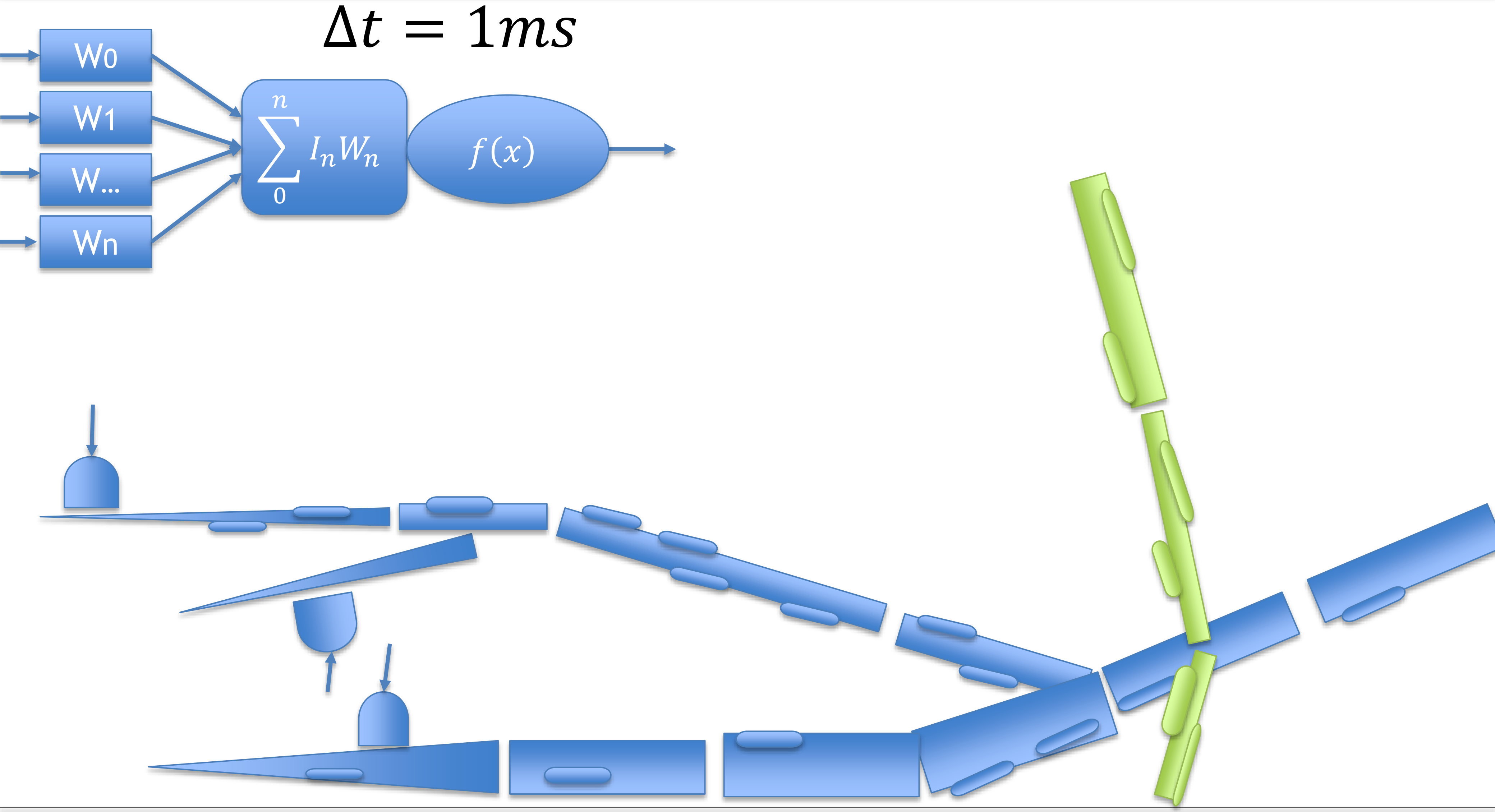

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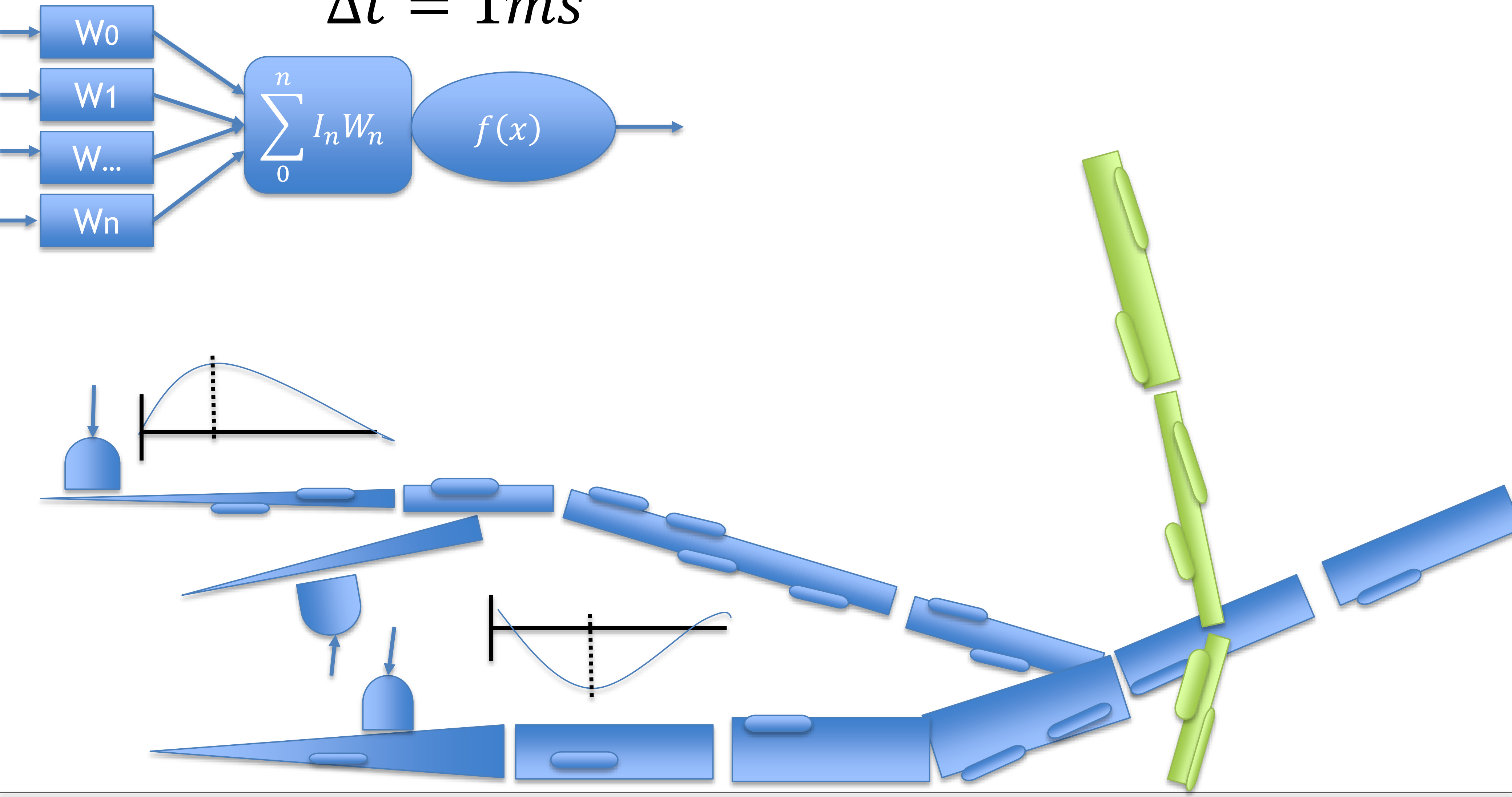

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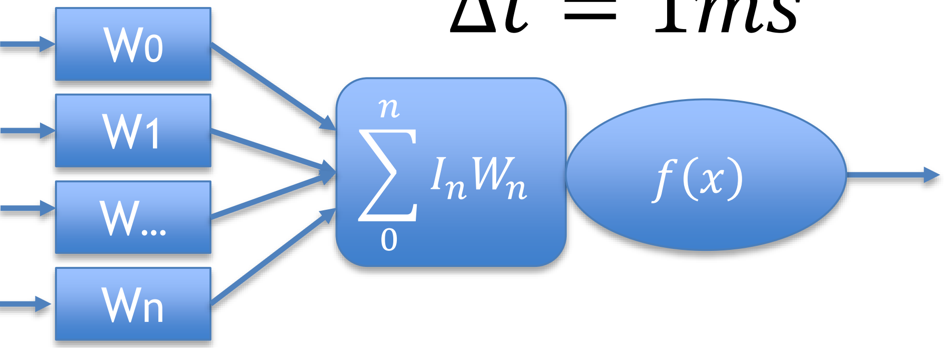

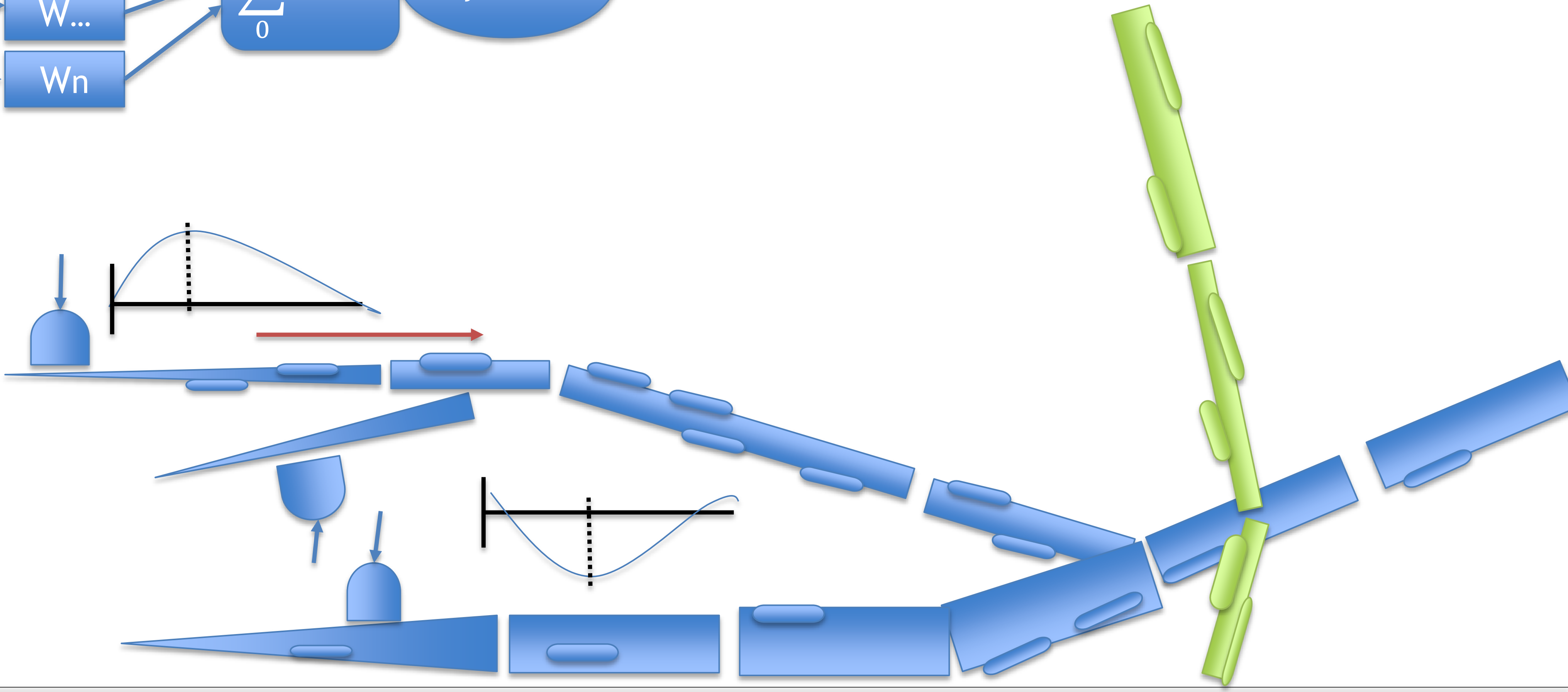

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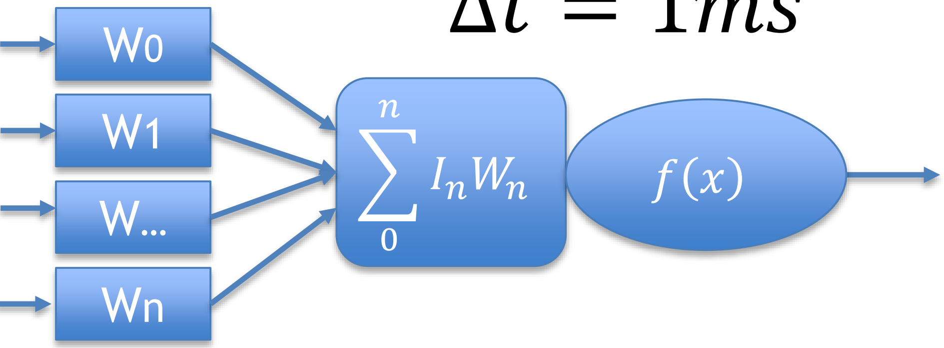

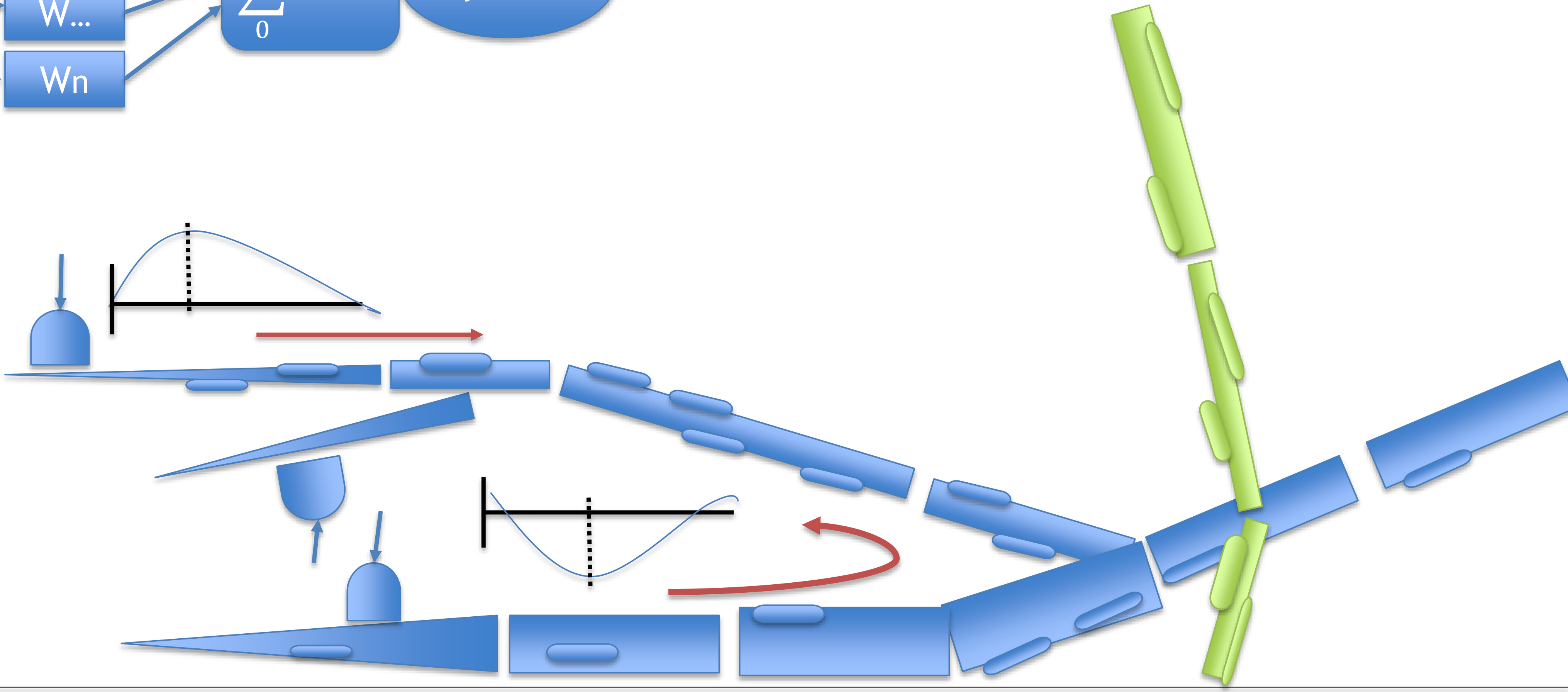

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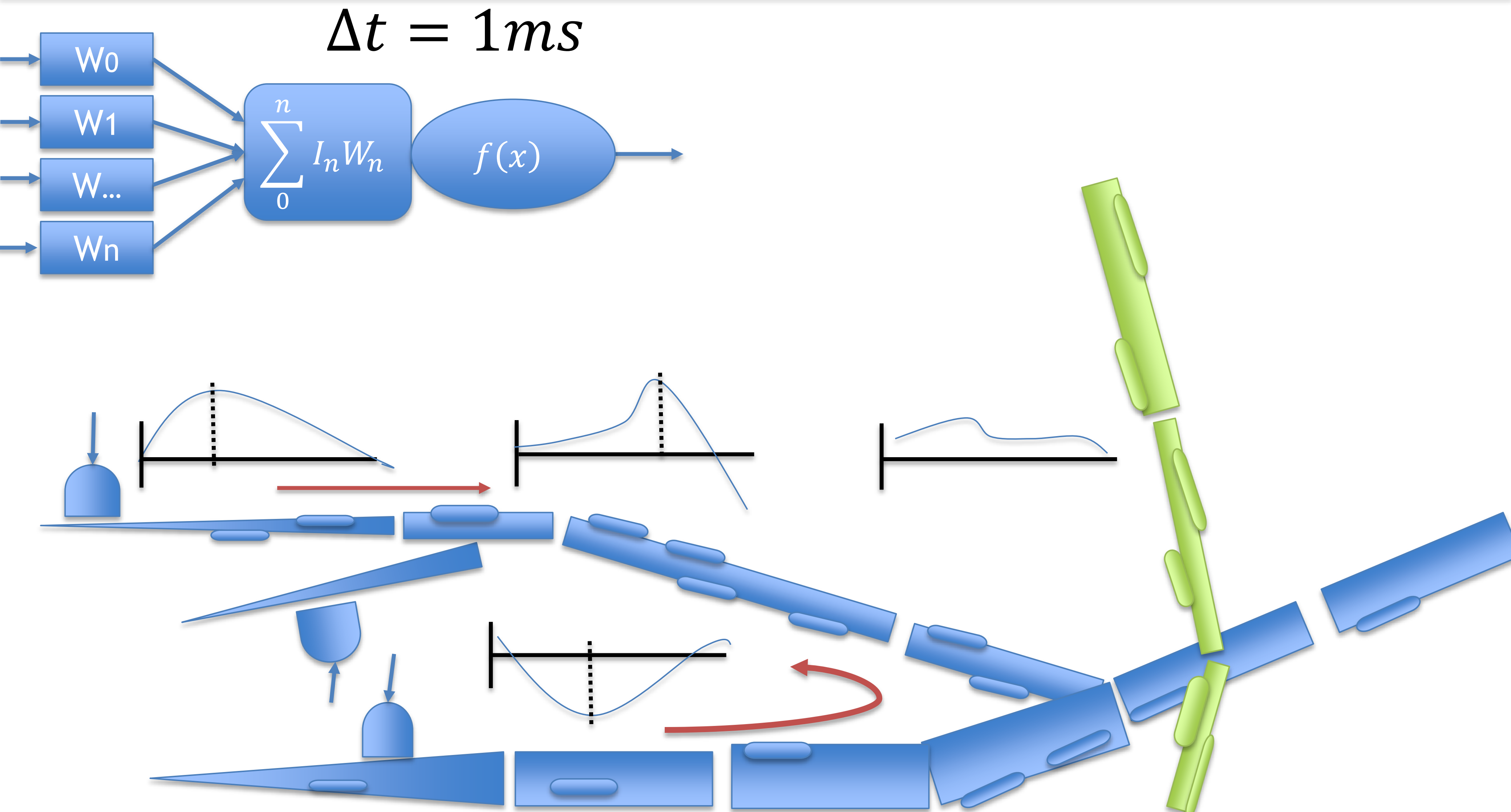
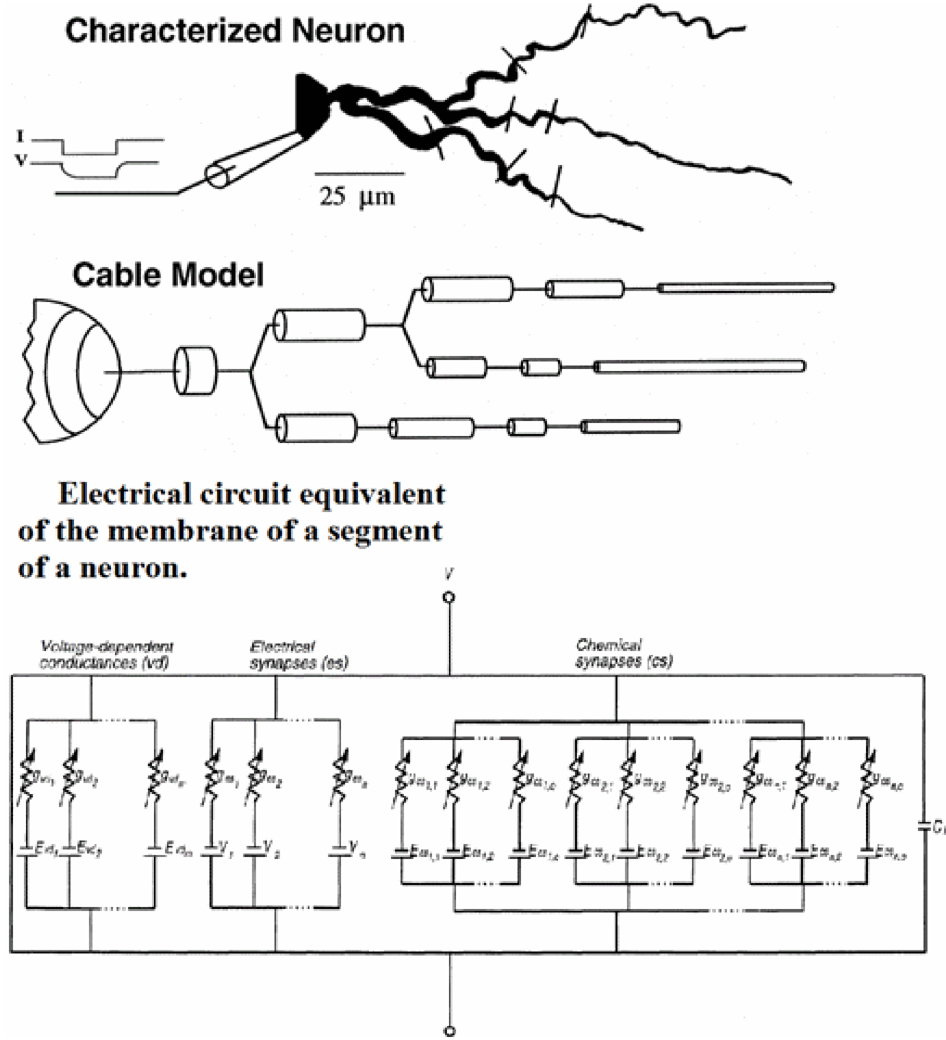


NestMC

- Basic unit of modeling frustum
- Balance the currents
  - Synapses, voltage dependent conductances (expensive)
- The magic sauce:
  - Almost all calculations are completely independent
- Parallel at multiple levels
- Redistribution and segmentation for coalesced memory access

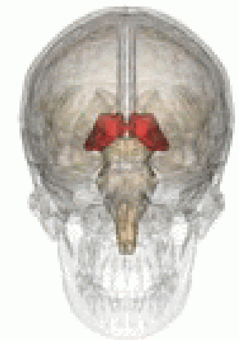


NestMC - Why?

- Existing simulator have a long history and large ‘essential’ feature space
  - Technical debt
  - Refactoring for Highly parallel architectures is non-trivial
  - Not all features work in highly parallel setting
- The opportunity to build for future HPC hardware:
  - Highly parallel architecture: intel KNL, GPU
  - Wide vector operations: AVX512
  - Specialized accelerator hardware: GPU, FPGA
- Co-design of new and complicated use-cases

Use-Case 1: Brain region

- Large scale simulation of whole brain regions: 4E6 neurons
  - Existing software requires large BGP cluster for simulation of 2E5
- Morphemically detailed neurons: 1000s of compartments
- Biologically detailed: Stochastic release of neuro-transmitters
  - Large number of random numbers
- Models are described in existing language: NMODL
  - Support existing interfaces



Use-Case 1

- **Close contact with the science team:**
  - Joined slack channel and open source code
  - Creation of project goals based on analysis. Setting of priorities by scientist
  - Validation of results, programmatically and by scientists
- **Examples:**
  - Kinetic schemes for stochastic models. Essential for model thus has the highest priority
  - Random number generation. After discussion alternative method designed

Use-Case 2: Cortical dynamics

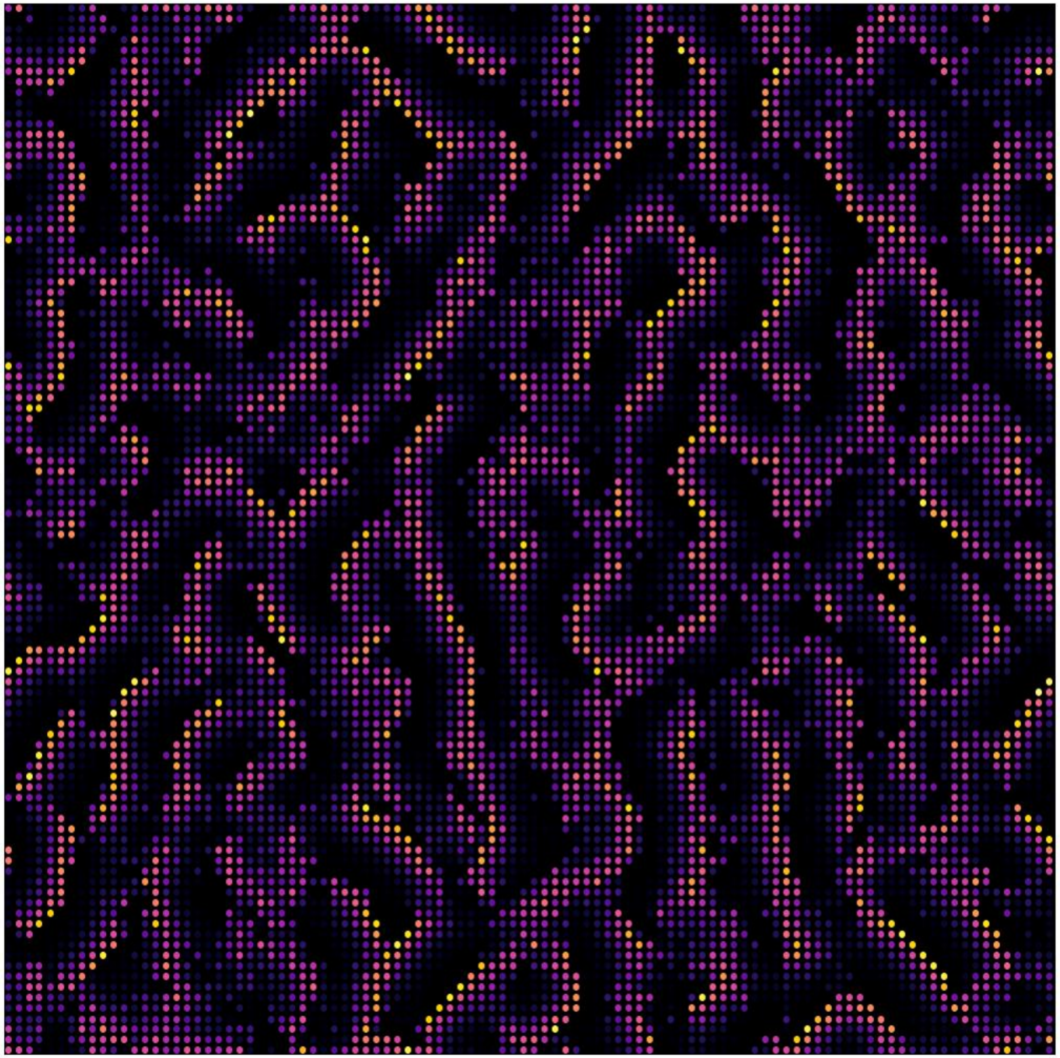
- Dynamics of large cortical network with biological density
  - 50000 neurons per mm2 dynamics occur on > cm2 scale
- Influence of synapse location
- Partially simulation of the cortex
  - Injection of random currents
- Existing models are implemented in existing simulator
  - Support of existing Python interface (NEST)

Use-Case 2

- Neuroscientist joins developer team
  - Translation of science use cases into requirements
  - Part of normal development cycle. Work on unrelated issues (strength in numbers)
- Examples:
  - Review of existing models in neuroscientific literature
  - Implementation of proof of concept with proto-type code, 4 days effort for a working model
  - Implementation of Poisson generator with biological characteristics.
  - Hackaton planned to add Python support

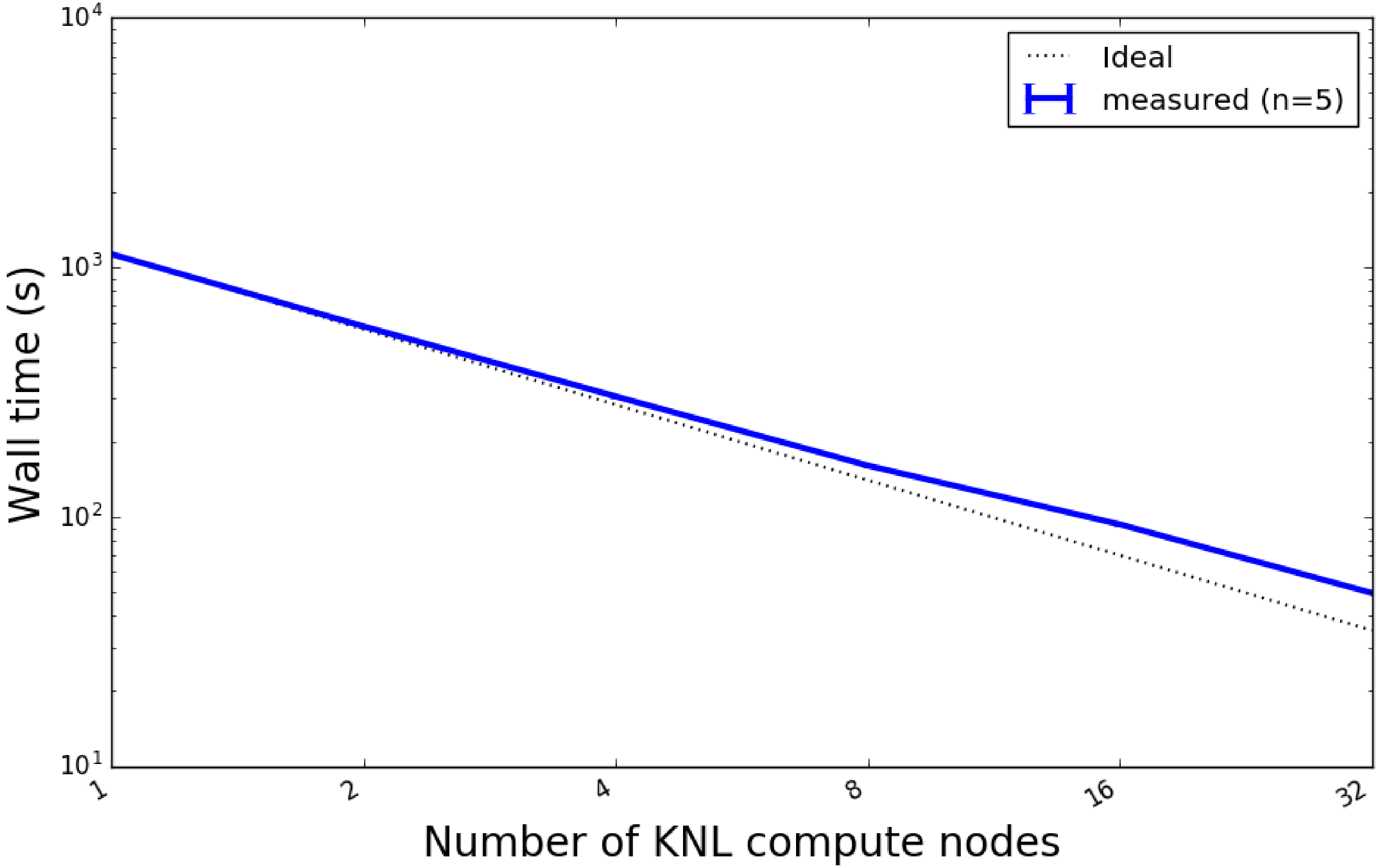
Use-Case 2

- 100001 Neurons
- 100 compartments
- 90 connections per neuron in a biological plausible ‘Mexican hat’ activation
- Each neuron gets random input from 1000 neurons



Prototype strong scaling Julia

- Tread occupancy 95% to 99.5%



Use-case lessons learned

- Our working model is loosely based on the AGILE / SCRUM methodology
  - Scientist as stake holder
  - Use-case driven
- You need buy-in from developers and scientists
- Compared to industry more ‘discussion’ with ‘management’
- Access to the hardware allows rapid iterations in development cycle
- Bleeding edge technology features are not yet discussed on stackoverflow

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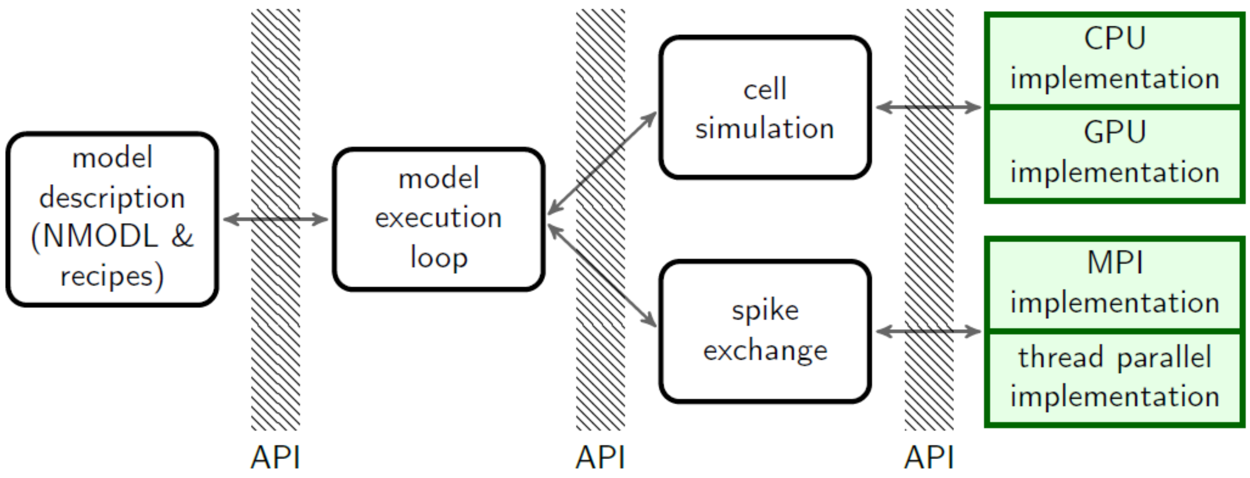
Human Brain Project

Thank You

www.humanbrainproject.eu @HumanBrainProj Human Brain Project

Prototype design

- Modular: Components can be easily exchanged according to internal API
- ‘Thin’ API via type parameterization to allow low – overhead data communication (internally and externally)



Prototype status

- Finite-volume based discretization
- Distributed model instantiation
- Spike and voltage trace output
- X86 multi-core and Intel KNL
- Synapse and ion-channel descriptions in NMODL
  - Code generation
- Unit and validation testing suite
- GPU support (first iteration)
- Open source: https://github.com/eth-cscs/nestmc-proto

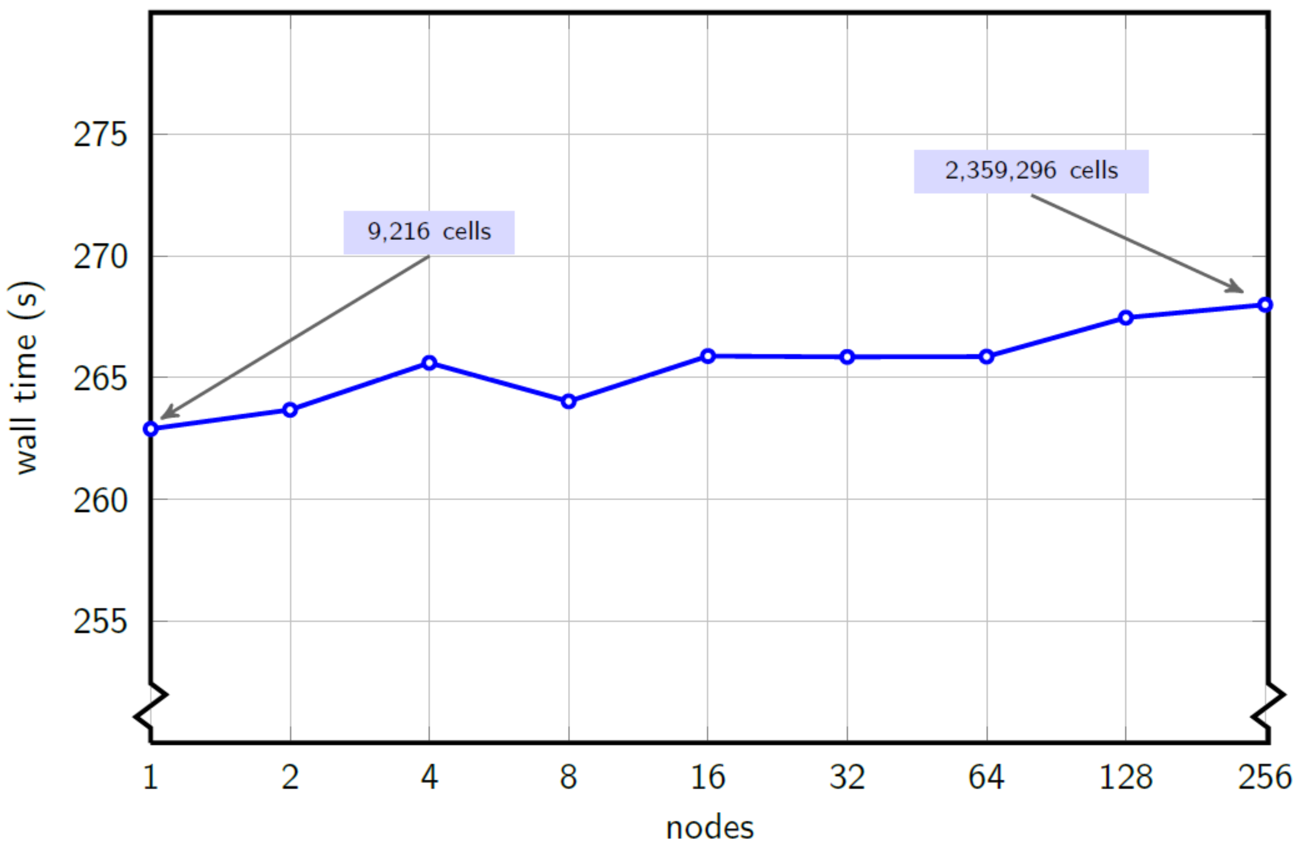
Prototype benchmarks

- Test case
- 500 ms simulation
- 350 compartments per cell and 2000 synapses
- HH mechanism on the cell some, passive dendrites
- Random network
- 50 Hz spiking rate

- 36 Core Cray system

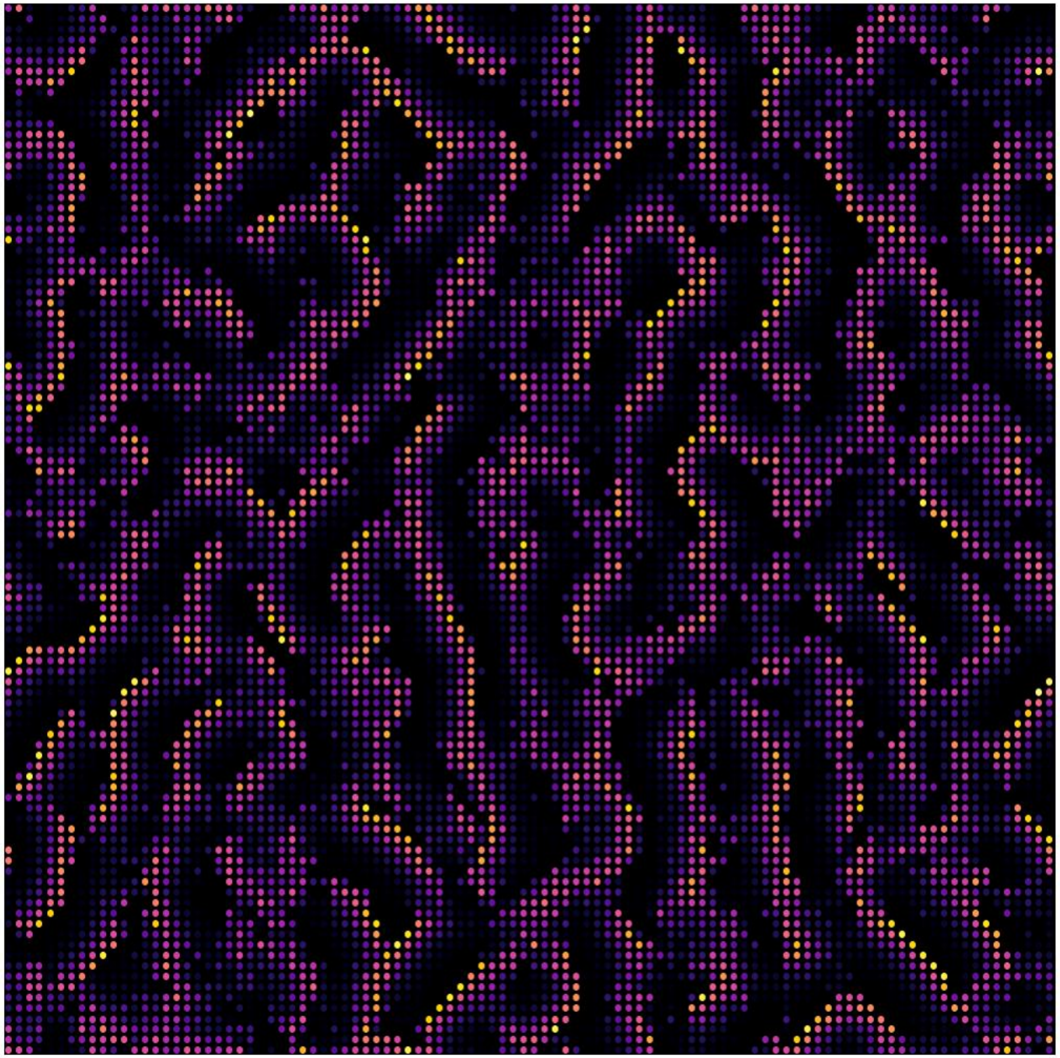
Prototype benchmarks

- Weak scaling



Use-case Pilot system benchmark

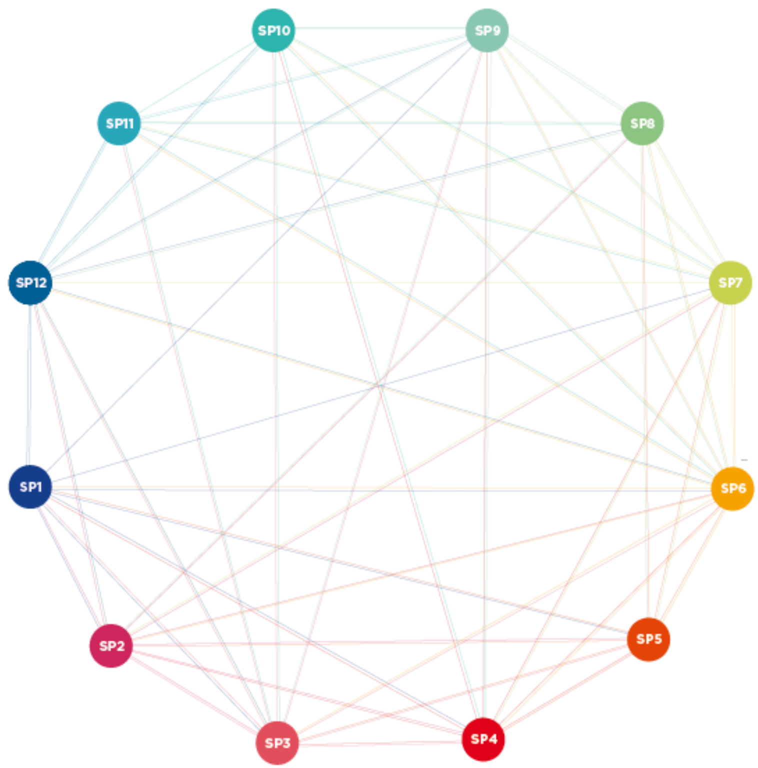
- 100001 Neurons
- 100 compartments
- 90 connections per neuron in a biological plausible ‘Mexican hat’ activation
- Each neuron gets random input from 1000 neurons



Human Brain Project

- Organized in twelve subprojects to further six informatics based platforms

Neuroinformatics	**Neuromorphic Computing**
Brain Simulation	**Neurorobotics**
Medical Informatics	**HPC**



Brain organisation
Cognitive neuroscience
Theory
Ethics and society
Management

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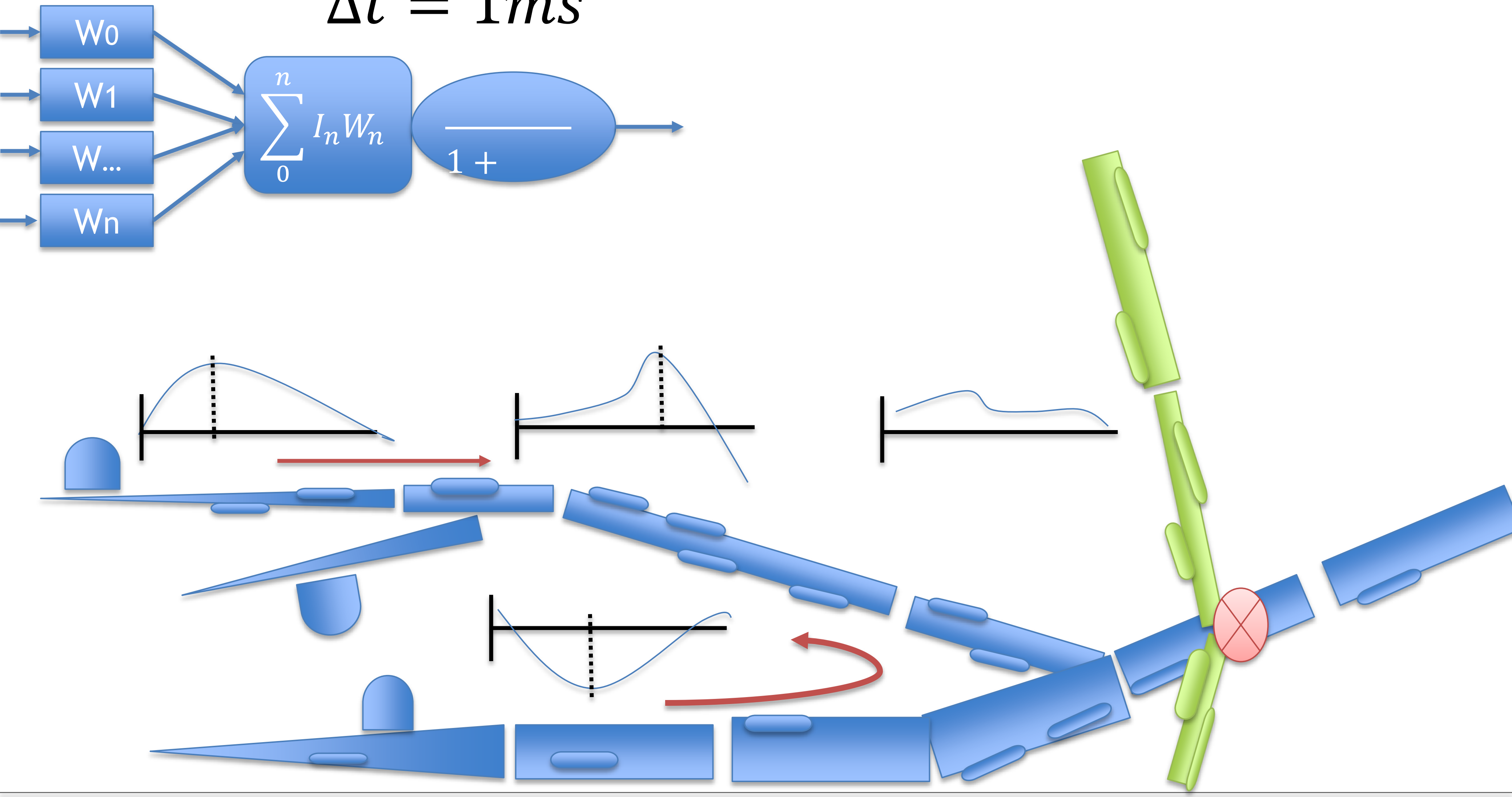

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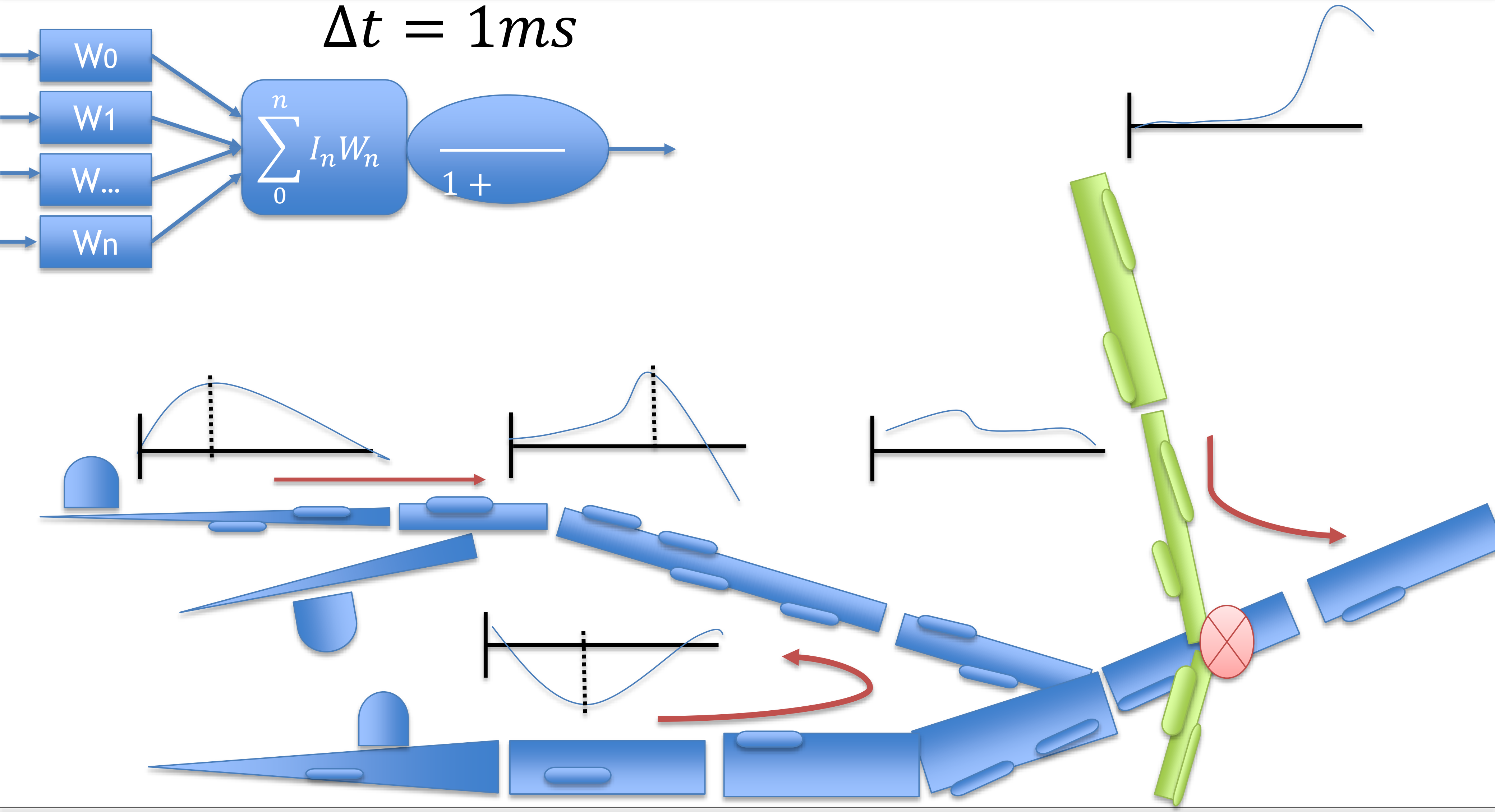

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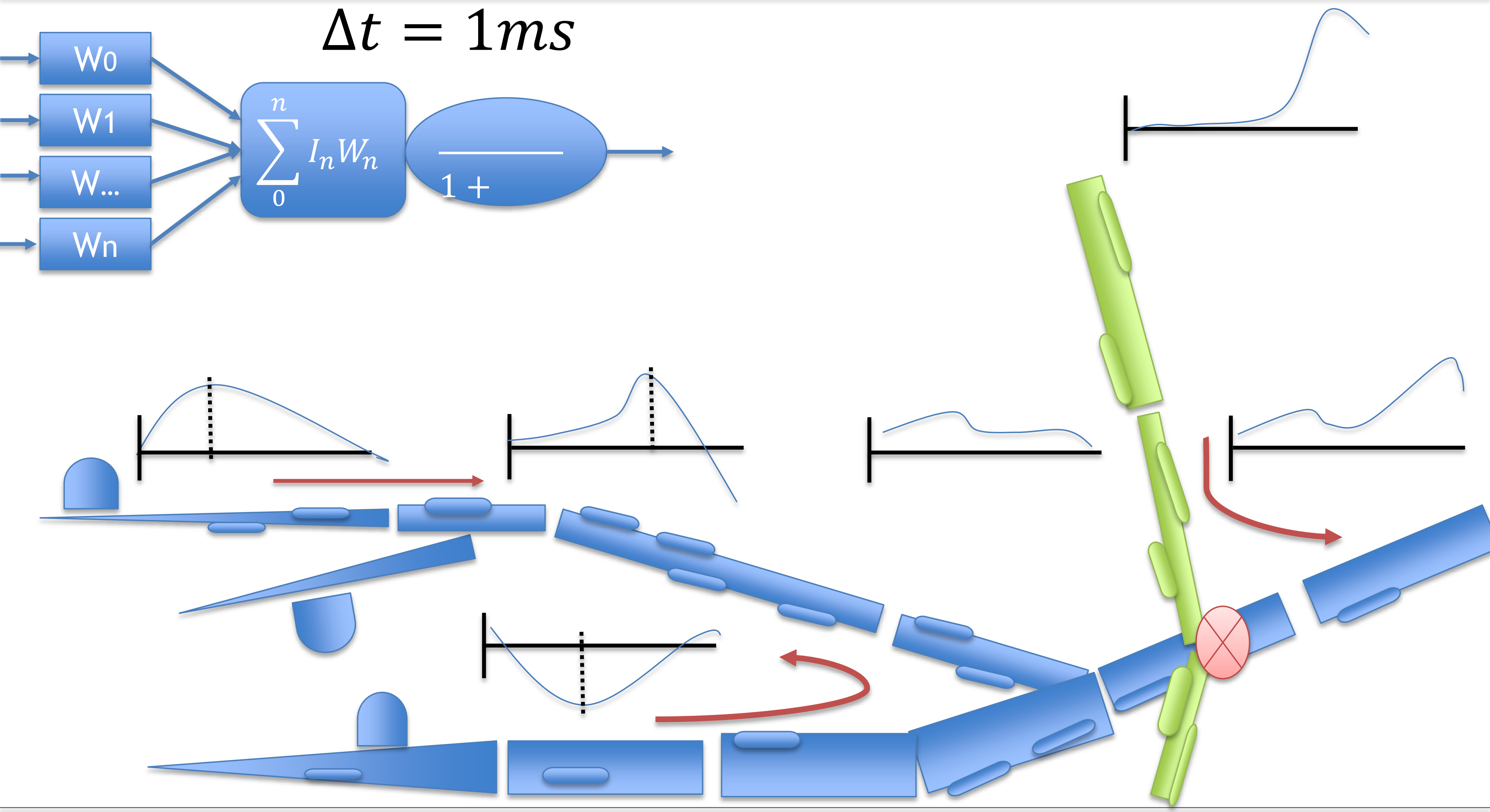

NestMC vs Artificial Neuron